Renewable and Sustainable Energy Reviews 16 (2012) 1516–1527

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Possibility of efficient utilization of wood waste as a renewable energy resource in Serbia

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ARTICLE INFO

Article history:
Received 23 August 2011
Accepted 27 October 2011
Available online 18 January 2012

Keywords:
Renewable energy
Woody biomass
Wood residues
Briquettes
Bio-fuels
Serbia

ABSTRACT

Wood biomass in Serbia is traditionally used for energy. However, the manner of its use is outdated, and efficiency is very low. Annually over 3.5 million m^3 of wood is cut down for energy needs in Serbia. In order to better exploit all forms of woody biomass, especially the one that is now treated as waste, and in order to fulfil the obligations from the outlined Convention on Climate Change it is necessary to switch to a modern way of production and utilization of woody biomass. Serbia is now at the very beginning of this process. This paper gives an overview and an analysis of the possibilities of utilization of wood waste as a renewable source of energy and the problems that producers in Serbia are facing due to undeveloped markets and excessive funds that are needed to start the production of briquettes and pellets. The ecological and economical advantages of using woody biomass, as well the possible support measures for the use of woody biomass in Serbia are also the topic of this paper. The present situation in this area, the manner of waste management in sawmills and the reasons for the necessity of future development of this industrial production are also briefly described.

Contents

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doi:10.1016/j.rser.2011.10.017

1. Introduction

Energy and bio-energy are becoming increasingly interesting and important subjects for the public, policy and decision makers due to increasing fossil fuel prices and growing concerns related to the use of nuclear energy. In addition, all the present concern for the environment encourages the use of alternative and renewable energy sources, especially in developed countries. This attitude was the stronghold of the Kyoto Protocol (1997) which was signed under United Nations Framework Convention on Climate Change. The sustainability of natural resources is a topic that encompasses economic, environmental and socio-cultural elements. When it comes to exploitation of forests, sustainability means that the forests and the benefits they bring to current generations should not compromise the possibility that the future generations benefit from them in a similar manner. Woody biomass can be a sustainable source of energy, precious renewable alternative to the limited supply of available fossil fuels [1]. The focus of initiatives for bio-energy is to ensure that the use of the land for bio-energy is economically, environmentally and socially sustainable.

Due to increasing demand for energy the fear of the risk of exhausting fossil fuel reserves worldwide is justified. As a result, the use of alternative, particularly renewable energy sources is gaining importance in the world ever since entering the first serious energy crisis [2]. One of the renewable energy is the biomass. Biomass certainly represents a competitive fuel that can be successfully used to produce energy, primarily in the processing of wood and the larger agricultural producers who have large quantities of biomass can take advantage of the bio-waste from their manufacturing process.

The production of biomass is at a high level in Europe, the technology has advanced, so more and more attention is given to improving the environment and especially the improvement of living conditions; the focus is increasingly on alternative fuels that have low levels of air pollution [3]. Instead of the usual types of fuel, the various types of bio-fuels are being used, derived precisely from agriculture residues. The remains of agricultural production, which amount is large, generally are not used, especially straw from wheat, soybeans, rye, sunflower and corn residues [4–7]. The energy potential of biomass from agricultural crops is about 1 million tons of oil equivalents. In addition to these residues a large amount of waste in the orchards, vineyards and livestock breeding should be also noted.

In Serbia, on average, every year we have 12.5 million tons of biomass, and in Vojvodina, about 9 million tons. If only a ¼ of biomass would be used for energy purposes, we could save around 1.3 million tons of equivalent fuel oil (Diesel D2). So much fuel is used for agricultural purposes throughout the Republic of Serbia [8].

Forest biomass for energy is one of the most important energy sources, given the raw potential and the possibility of renewing them. Most countries in the world accept the fact that it is necessary to increase the share of this energy in total consumption using various measures. The use of forest biomass as a renewable energy source is gaining importance in the world and it is expected to be so in the future in Serbia too. The reason is not only the advantage of this type of energy from an environmental point of view, but a reality that there are fewer and fewer non-renewable sources of raw materials and energy needs are growing. Use of forest biomass for energy demands modern technological solutions in order to cut down production costs to the lowest possible level. This is primarily related to technical solutions when collecting, packaging, transporting, storing, drying and grinding the forest biomass [9].

In Serbia today, the use of forest biomass is not at an appropriate level for several reasons, taking into consideration the raw material base and the possibilities of its expansion. For the significant use of biomass it is necessary to ensure, first of all, legislative and administrative conditions. They must contain all the measures of state policy, from the national energy program and strategy for its implementation to the specific tax incentives and subsidies. It is necessary to engage the scientific and professional personnel, who would not only point out the importance and the advantage of using this type of energy, but also participate, in the development of national standards for bio-fuels and equipment for their use. All this involves a detailed analysis from the economic and ecological aspects.

Raw material potential of forest biomass of Serbia can be increased by raising new forest areas, particularly by establishing dedicated short rotation plantations on forest and agricultural land. Production of briquettes and pellets is more advanced in the countries of the European Union, especially in the Scandinavian and Alpine countries that are rich in timber. In previous years, by strengthening the trend of environmental protection, the importance of this type of energy production has spread to the rest of the European Union [10], and as a result the mass production of briquettes and pellets, which are used for energy production and in everyday use (individual furnaces), has begun. In developed countries, wood pellets are used more and more because they have excellent economic, environmental and energy characteristics.

The current consumption of energy in Serbia stands at 15 million tons of oil equivalent (Mtoe), on the other hand it is estimated that Serbia has 3.2 Mtoe of renewable energy which is used in negligible amounts [11]. Of the estimated amount of biomass (which is 2.6 Mtoe) 60% refers to biomass of agricultural origin, while 40% comes from forest biomass.

2. Materials and methods

Our choice of research led to the application of corresponding method of operation. In preparing this paper analytic and synthetic methods were used, as well as statistical and mathematical instruments. As a source of data the literature concerning the production and use of biomass was used. To determine the energy potential of woody biomass residues the newsletters of "Srbijasume" were used with consultation of expert literature.

The data of the Republic Statistical Office about the forest area in the municipalities in Serbia were used for writing this paper. Based on these data and with the help of the computer program ArcGIS 9.2 a map of forest representation was drawn that enabled detection of geographical areas with higher percentages of forest and therefore the greater exploitation of forests and more developed wood industry.

The empirical research was conducted at the sawmill DIV-Chabros in Loznica, in western Serbia. Field-based analysis shows the amount and type of wood that is processed in the sawmill DIV-Chabros, the residues from the production and the calculations of waste that remains in the production process.

The aim of this work is to explain the significance of using, as much as possible, biomass as a renewable source of energy,

particularly woody biomass, which represents the environmentally friendly fuel that is produced from renewable sources, making the wood fuel one of the solutions for reducing the emission of greenhouse gases.

3. Types of biomass and the importance of use

Biomass is the degradable part of the products, waste and scrap of vegetable and animal origin, whose energy use is permitted in accordance with the legislations that regulate the protection of the environment. These are all those substances that occur as a by-product, and are subject to very rapid natural deconstruction [12].

The biomass include products obtained in the field of forestry, residues and waste from forestry, products and residues from the agriculture, horticulture and viticulture obtained from pruning, products of agriculture, livestock breeding and correlating industries, as well as the biodegradable part of industrial and municipal waste [13]. The biomass can be used in the production of biogas, bio ethanol and biodiesel, as well as getting heat and electricity [14].

The most significant use of biomass in Serbia is in warming up households and buildings by using briquettes and pellets from biomass, which is environmentally and economically feasible. Serbia has the potential to produce about 4 million tons of oil equivalents, or about half of primary energy, which in 2009 totalled 8.79 Mtoe. Annually around 0.86 Mtoe is produced from renewable sources, and only 18% of the total potential is utilized and it is almost entirely used for the production of electricity in large power plants.

Biomass is, as it is said, renewable energy, fuel that is derived from plants or plant parts such as wood, straw, stalks of grain and so on. It can therefore be divided into wood, non-wood, animal and municipal and industrial waste, within which one can differ:

- woody biomass (forestry residues, waste wood),
- grown wood biomass (fast growing trees),
- grown non-wood biomass (fast growing algae and grass),
- residues and waste from agriculture (straw, corncob, pruned branches, old vines and old trees),
- residues in the food industry (fruit seeds),
- animal waste and residues,
- communal and industrial waste [15].

Application of biomass for energy production takes place respecting the principle of sustainable development. In conditions when the ethanol and biodiesel are produced from food, in terms of the explosive increase of world hunger, the application of biomass for this purpose shall be subject of a very serious analysis, especially from the viewpoint of strategic logic of energy [16,17]. Wood mass that is formed as a by-product or waste and residues that can no longer be used are the most commonly used. Such biomass is used as fuel in power plants and for producing thermal energy or it is processed into gaseous and liquid fuels for use in vehicles and households [18].

According to the Ministry of Mines and Energy, the biomass could produce a quarter of the total energy produced in Serbia [19,20]. The energy potential of biomass in agriculture is estimated at around 3 million tons in crops, and in orchards and vineyards around 1.1 million tons [21]. The potential of renewable energy from forestry is also not negligible. In Serbia, there is a growing acceptance of so-called energy forests on around 200,000 hectares of uncultivated land, which could be planted with fast-growing trees that can be used for energy purposes.

Researches show that the annually production could achieve a yield of 15–20 t of woody biomass per hectare, in other terms – between 3 and 4 million tons of woody biomass. Fast-growing forests that are planted specifically for biomass production in Serbia do not exist, and this issue should be included in a regular program of public enterprises and all forest management companies. In that way the production of woody biomass would be encouraged and intensified, which would positively impact the growth of economic development at the local level and therefore at the state level [22].

Table 1
Ash and sulphur content caused by burning different kinds of trees.

Kinds of wood	Participation in %		
	Ash		Sulphur
	Xylem	Bark	
Beech	0.36	2.29	0
Linden	0.32	0	0
Oak	0.36	6.68	0
Fir	0.42	1.16	0
Spruce	0.39	2.23	0
Black pine	0.20	1.05	0

Source adapted from Ref. [30].

Woody biomass is environmentally friendly fuel that is produced from renewable sources. Emission of harmful gases, especially CO_2, during combustion of fuel based on woody biomass is minimal [1,23,24]. Therefore, the fuel obtained from wood is one of the solutions to reduce greenhouse gas emissions [25]. At the time of energy and environmental crisis the biomass becomes an important material in various technological processes, as well as cheap source of energy in industry and household. By adopting the Kyoto Protocol within the Convention on Climate Change (The Kyoto Protocol under the United Nations Framework Convention on Climate Change) Serbia undertook obligations in order to stabilize the concentrations of gases that make the greenhouse effect and by doing so Serbia got involved in addressing this very important issue at the global level [26,27].

The use of biomass for energy purposes has many advantages, some of which are:

- environmentally friendly fuel that can make a significant contribution to efforts to reduce CO_2 emissions;
- renewable energy source with the application of measures for sustainable forest management;
- reducing dependence on imported energy;
- ensuring economic development in rural areas, which is of great importance for uneven regional development in Serbia [28].

Wood production in industrial plants is ecologically sound, unlike some other types of industry. No chemicals are used, there is no hazardous waste, and the machines used for production cause only a small level of noise. Although modern sawmills have wood dryers for steaming the wood, they are not they are not polluters if they meet all the standards ordered by the authorities in the field of environmental protection. Otherwise, they can highly pollute the environment. Using woody biomass as fuel is justified from an environmental and energy aspects [29]. When burning wood remains of ash and sulphur, substances that contribute most to environmental pollution, are minimal. Table 1 shows the contents of ash and sulphur in the burning remains of various species of trees.

Using and combusting fossil fuels leads to a much larger environmental pollution (Table 2). In fact, their use relieve different kinds of gases in the atmosphere (carbon dioxide, methane, sulphur hexafluoride, etc.) which cause greenhouse effect, in other words – global warming and climate change. The use of renewable resources leads to reduction of the amount of gases – it is an attempt to reduce the creation of other harmful substances (such as ash and sulphur). Wood is the cleanest and safest fuel, which is explained by the fact that this fuel is has a low content of nitrogen

Table 2
CO_2 emission during fuel combustion.

Type of fuel	CO_2 emission in kg/kWh of energy
Gas	0.19
Gas in bottles	0.23
Mazut	0.27
Coal	0.29
Timber	0.03
Wood pellets	0.03
Briquettes	0.03

Source adapted from Refs. [8,31].

and sulphur, in contrast to other fuels, especially when compared to using coal, oil and petroleum products [31].

The highest CO_2 emissions is achieved by coal combustion (0.29 kg/kWh of energy), followed by oil and gas in bottles, while the lowest level of CO_2 emission is achieved by combustion of wood, whether it timber, briquettes or pellets with the percent of only 0.03 kg/kWh of energy (Table 2).

A typical energy balance for the systems in forestry and agriculture indicates that 25–50 units of bio-energy are produced for every unit of fossil energy consumed in production. Liquid bioenergy production requires more energy input, which is roughly equal to four or five units of energy produced for every unit of fossil energy consumed. Net carbon emissions from the production of one unit of electricity from bio-energy products are 10–20 times lower than emissions from electricity generation from fossil fuels. Kyoto Protocol encourages policies that are aimed at limiting emissions of greenhouse gases, especially carbon dioxide. The two main reasons for the increase in CO_2 concentrations are the burning of fossil fuels and changes in the use of land, especially deforestation. Bio-energy offers many opportunities to the society to reduce emissions of greenhouse gases by replacing fossil fuels and intensifying reforestation instead of deforestation [32].

The current structure of primary electric energy sources cannot, on a global scale, provide a trend of increasing energy production. Global energy crisis and global environmental problems are closely related. In fact, these two problems are nowadays treated as one – obtaining ecologically clean energy ("green energy"). Ecological problem and the problem of exhaustion of fossil fuels, on one hand, and increasing demands for energy on the other hand, forced highly developed countries to invest huge funds and employ a large number of experts in the development of renewable energy technologies. Constantly increasing price of fossil fuels like crude oil, natural gas and coal encourages greater use of biomass as a cost effective alternative energy source, which is renewable, environmentally clean and present in large quantities. In accordance with that energy from renewable sources has a special place by contributing to the possibility of sustainable development of society [33].

4. Raw material potential of wood for energy in the forest of Serbia

Forest areas in Serbia are widespread. The forests are spread over all the major mountains, with fewer forests in the territory of Vojvodina, except for small areas on the Fruska Gora and Vrsac mountains.

The increasing diversity of use and expectations of the public related to forests have led to the fact that the concept of sustainable forest management became the main objective of forest management. Sustainable forest management has yet to be defined, but the government and other organizations have developed criteria and indicators in order to evaluate a range of activities in forestry and to adapt the managing to those activities [34]. Ecological criteria assess the health status, productive capacity, biodiversity, land, water, nutrients and carbon dioxide levels. Economic criteria are used to estimate employment rates, the price of wood and other forest products, and social criteria is used for factors such as public participation in decision-making in forest management and use of forests for their spiritual and aesthetic characteristics. All these factors combined allow the assessment of viability. As the woody biomass for energy is a forest product, its monitoring can be done with the use of criteria and indicators in order ensure sustainability. Certification carried out by an independent body which verifies that the products obtained from forests on land that is managed in a sustainable manner is another element that increasingly affects the production of biomass for energy. Certification is done to ensure the constant availability of public forest lands through improved acceptance of forestry activities by the public. In some countries a certified environmental system for the production of energy is used for "green marketing". As "green energy" is more and more accepted so will the trend of certification become stronger [28,32,34].

Public enterprises *Vojvodinasume* and *Srbijasume* are responsible for forest management in the entire territory of Serbia. *Vojvodinasume* is responsible for forests in the AP of Vojvodina, while *Srbijasume* is responsible for forests in the remaining part of Serbia. Four national parks are not under the jurisdiction of these two companies. These are Fruska Gora in Vojvodina and Tara, Djerdap and Kopaonik which are located in the western, eastern and southern Serbia, respectively. National parks are public companies and they manage forests on their territory.

Origins of the legal protection of forests in Serbia date from the 14th century. Article 123 of Dusan's Code of law from the year 1349 forbade the Sas miners the logging of forests and defined the duty of planting trees in areas where forests have been cut [35]. The first Law on forest was passed in 1891, which is the beginning of organized labour in forestry. In 1991 for the first time in history of Serbian forestry most of the forests were entrusted to a public company – Srbijasume, which provided an opportunity to, with the use of a unique methodology, carry out land surveying which was used to define further actions with forests [36].

Today the major problem are the forest areas that are degraded, which is why forest management is important, along with prescribing and respecting all the measures ordered by the experts. The Public Enterprise for Forest Management *Srbijasume* launched the project "Sustainable forest management certification according to the FSC (Forest Stewardship Council) program," which is funded by the Ministry of Agriculture, Forestry and Water Management of Republic of Serbia. The project was initiated because of sustainable forest management in accordance with the principles of environmental protection, market demands and development of relationships with stakeholders, with positive economic operation. The certificate guarantees that the product originated from forests which are managed in an environmentally sound, socially just and economically viable way. By fulfilling all three conditions, the certificate can be obtained by anyone who is engaged in forestry activities or is in some way related to forestry and products from forest [35,36].

4.1. Forest fund of the Republic of Serbia

The area of Republic of Serbia is 8,836,100 ha. The total area of forests and forest land is 2,429,642 ha. The percentage of forest cover in Serbia is 27.5% and varies by individual regions: Vojvodina has 6.8%, Central Serbia 32.8%, Kosovo and Metohija 39.4%. Serbia's forested area is close to the global value which is 30% but it is significantly lower than European value which reaches 46%. Of the total area of forests and forest lands the state owns 50.91% and 49.09% is in private ownership. Timber stock in forests in Serbia is around

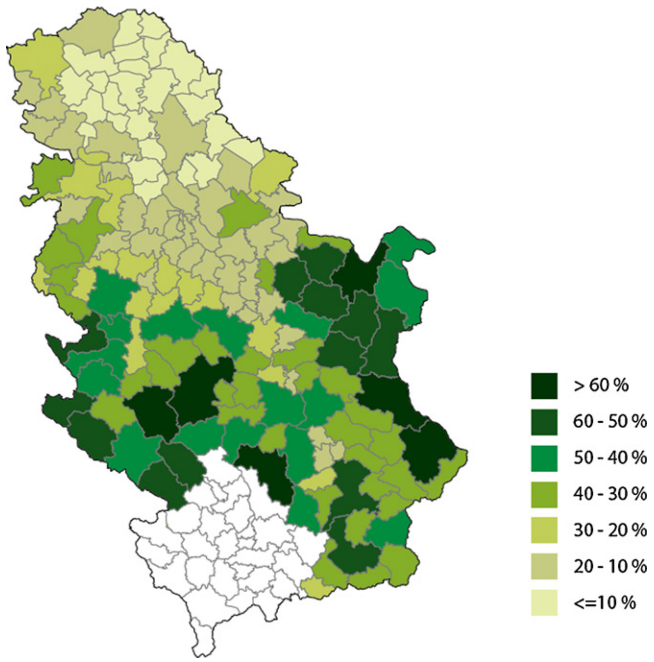

Fig. 1. Forests in the Republic of Serbia.
Source adapted from Refs. [38,39].

235 million m^3, or 101.6 m^3/ha, and the current (annual) volume increment is about 6.2 million m^3, or 2.67 m^3/h [37].

Of the total timber reserves around 90.1% is from deciduous trees, and 9.9% is from conifer trees. The most common tree species is beech, which occupies 50.4% followed by oak with 25.8%. The most common coniferous species is juniper with share of 4.4%, followed by fir (2.9%) and pine (2.2%) [35,37].

Layout and density of forests in Serbia (Fig. 1) shows that most municipalities in Serbia have in their area a forest fund, which ranges from 20% to 40%. The municipality in which the forested area are greater than 50% are numerically smaller, and they are mainly in Eastern and South-East region of Serbia, mountainous areas of southern Serbia and in central parts of the Republic [38,39].

The relationship between the volume of harvested wood and volume increment of wood in the forests of Serbia is around 50%. Countries with developed forest infrastructure, with good forest management have up to 75% utilization from the annual wood increment in forests. By improving the infrastructure in the forests Serbia could increase the potential for sustainable use of wood in the forests. According to the Spatial Plan it is envisaged that by the year 2050, 41% of Serbia's territory should be covered by forest. This value is estimated as the optimal forestation of Serbia. To achieve this goal, the forest areas should increase each year for 29,000 ha. During periods of intense afforestation during the eighties, afforestation was around 20,000 ha annually. Afforestation conducted in Serbia in the past few years (2002–2006) shows that the intensity of afforestation is lower than it should be – it is only 5300 ha per year. This increase should allow proportionally greater volume of tree cutting for about 6.900 m^3. State land and forests are almost completely afforested with forest trees. According to executives of *Srbijasume*, state forests can be increased only by 10%. Most of the land that has to be afforested is in private ownership [34–39].

4.2. Energetic, fast-growing forests in Serbia

Fast-growing tree species are very suitable for production of wood for energy, since they have a short production cycle. Energy plants are used as a substitute for fuel in heating systems. They replace light heating oil (distillate oil) and reduce greenhouse gas emissions by reducing the carbon dioxide emissions. Fast-growing forests are comprised of willow or poplar trees, which are harvested in 2–5 years, usually every 3 years. The planting of energy forests, their cultivation and maintenance, contributes to facilitated supply with biomass and raw materials suitable for the production of briquettes. Most commonly grown trees as energy crops are: willow (*Salix spp. L.*), whose calorific power is 19,380 kJ/kg with annual production of 213,488 tons per hectare. Perennial grasses grown as energy plants are: switchgrass (*Panicum Virgatum L.*), which has a better commercial success than other energy plants, a high yield and good quality of combustion, harvesting can be done every year and the calorific power is 19,900 kJ/kg; elephant grass (*Miscanthus giganteus*) with the calorific power of 19,135 kJ/kg it can survive a minimum of 15 years; giant reed (*Arunda donax L.*), provides a yield of 40 tons per hectare of dry matter, and has a calorific power of 18,035 kJ/kg.

Technological possibilities of using soft wood plants intended for energy production are very favourable from the organizational aspect, degree of mechanization, and ways of cutting, wood concentration per unit of area and so on. For the time being there are no energy crops in Serbia, but research and analysis show that the land not suitable for growing conventional crops could be perfect for growing poplar trees, which grow rapidly and can be energy crops. It is estimated that about 200,000 ha of land in the plains regions along the rivers and canals, that are not suitable for agriculture, could be used for fast-growing poplar trees. This is one of the possibilities for increasing the energy potential of wood in Serbia. For example, the most productive tree species in dry habitats is acacia, whose potential increment is 7 m^3/ha per year with the production cycle duration of 15 years. In the semi-damp habitat most suitable type of trees are the newly selected black poplar varieties, which have the production potential of about 30 m^3/ha per year in a very short production cycle of 7 years. In the wetlands the American ash tree gives the annual increment of 8 m^3/ha per year, which is high for clay soil that is burdened with excessive moisture [40].

4.3. Wood production in Serbia

Wood production in Serbia is expressed by wood cutting, which, in the official statistical bulletins, include all commercial assortments of wood and wood wastes. Wood cutting in 2009 in Serbia was 2,609,494 m^3 in the forests, and an additional 25,000 m^3 outside forests (parks in cities, trees along roads, canals, boundaries) which gives an overall logging of trees of about 2.63 million m^3 of timber [38,39].

Assortments resulting from wood cutting are: cut wood for further cutting and manufacturing various kinds of technical wood, wood for support pillars in underground mines, wood for producing pulp and paper, firewood and other wood products including those for production of boards. The largest share (50%) of cut wood from state forests is used as fuel. The other half (50%) of cut wood from state forests is used for the production of furniture, in the pulp and paper industry, production of pillars and for other purposes. Despite the fact that almost half of the forests are in private hands, the volume of logging of forest trees in private forests is three times smaller than in the state forests. The probable reason for this condition is poor market for wood. As a result, private owners have no interest in setting up their own association in order to improve management of their forests. In addition to the tree trunk as one type of forest assortment, there are different types of waste that are used as biomass such as wood parts that fell off and those parts that remain after the processing of wood (Table 3). It is estimated that there is about 2.9×10^6 m^3 of biomass residues in forests, which has the energy value of 549,500 tons of oil equivalent [30].

Table 3
Average share of various categories of wood in the total volume.

Wood assortment	Share in the total mass (%)
Round wood	38
Stacked wood	30
Roundwood bark (bark peeled from wood for the market)	4
Forest scrap (residues of wood cutting in forest)	9
Small branches	11
Stumps	8
Total	100

Source adapted from Ref. [30].

Based on what was said earlier we can conclude that efficiency and profitability determine which parts of the tree and to what extent will be used. The amount of energy that will be obtained from the timber depends on the quality of the raw material. If the price of the wood waste was adequate, technical and technological problems of collection and transportation of parts of wood after cutting down the tree, which is currently one of the issues, would be resolved.

There are around 2760 companies involved in wood processing and furniture production in Serbia. The majority of them (2360) produce sawn timber, wood panels, veneer, joinery, and the remaining 400 firms produce furniture [38]. Over 90% of the total numbers of companies involved in this activity are small businesses. Most wood processing companies are sawmills, pallets and packaging producers, producers of windows and doors, and manufacturers of wood panels. A large number of sawmills are the result of available materials, relatively low capital investment and short payback period.

5. Waste derived from woody biomass

Wood waste is generated from different sources and can vary considerably in composition, quality and quantity. Each of these factors can significantly affect the possibilities for utilization of wood waste. In the past, contaminated wood waste was disposed at landfills or was burned, and cleaner waste was used in the production of boards. However, new technological advances and development of alternative markets have provided more options for further utilization of this natural resource. It is now possible to remove large amounts of pollutants from the wood waste and thus produce high-quality materials for various markets [41].

By cutting down forests bark, branches, leaves, discarded trees, roots, stumps, remnants of pruning, tree tops, and chips remain as wood waste. Another way of getting waste are both the primary and the final wood processing when the remains include cut lumber, bark, stubs, sawdust, veneer and plywood. By processing in carpentry and furniture manufacturing stubs, sawdust and other solid waste remain. Wood as a construction material also gives a certain amount of waste, namely: corners, chips, sheeting residues, old doors and windows, floors, fences, etc.

Landfills and other points for collection and/or classification of different types of waste are sources of wood waste. Those include municipal waste, residential, commercial, institutional and industrial products that were rejected, including durable and consumer goods, packaging, furniture, toys, wooden boards, pieces of wood and panels, waste from gardens and parks. Wood waste is generated during the production of furniture, but also at the end of the service life of the products when the office and household furniture is decommissioned. In the production of furniture timber is a significant part, and during processing a large part of it ends up as waste. Waste is often up to 60% of sawn timber and 25% of board materials. Final production can often produce further loss of 5% in stubs, assembly of the product 2% and packaging 15%. Due to large amounts of wood waste producers must strive to limit the cost of disposal, and wherever possible, make the best use of this material. Many factories are now burning the waste, using it for heating their facilities or as a source of electricity. However, there is considerable potential for alternative use of large amounts of wood waste from this sector [41].

There are estimated data for Serbia about the total quantity of available wood waste, where the classification in all categories is not done. In Vojvodina this quantity amounts to around 90,000 tons per year from forestry and 180,000 tons per year from wood processing. In the National Energy Efficiency Project for Serbia the amount of forest residues is estimated at around 2.9 million m^3, which is around 42% of the total weight of harvested wood and around 0.35 million m^3 of residues from wood processing (sawmill processing, production of veneer, chipboard panels, final wood processing and chemical processing of wood). These data refer only to the statistically processed logging and wood processing [32,41].

5.1. *Wood waste in forestry*

In the process of wood cutting, from the total volume of woos two types of products remain: technical wood and stacked wood, which is 90% of the total harvest; the remaining 10% is wood waste. A lot of debris like trunks, thinner branches, leaves and needles, whose share in the total amount of wood is around 2%, are left in the woods. Volume of unused parts, in the form of bark, thin branches and stumps, is about 42% of the total wood volume.

All of these residues can be used as biomass, mainly as a source of energy. What part of the residues will be used depends on the type of terrain, forest infrastructure and distance to the site of residue exploitation. In lowland forests, where access is easier, it is possible to use almost all of the residues after the cutting. In contrast, in mountainous areas, with large slopes and poor infrastructure, very little residues can be drawn out of the forest [41].

The possibility to use the restored wood from the waste depends mostly on its pollution with other substances and the possibility for their removal. Depending on the species, contaminants can be removed mechanically (bricks, tiles, floor coverings, linoleum, glass, plaster, mortar, soil, rocks, metal components, etc.), or by physical or chemical means (various organic protective means, waxes, oils, paints and varnishes, adhesives and other additives, water, etc.).

In case of clean waste, the selection of option for recycling is affected only by the size of the particles (pieces) and the type of wood. In general, reducing the size of the "pieces" and by increasing the destruction of the wood fibre the value of wood waste is reduced (wood dust is less valuable than chips that are suitable for production of boards or paper).

5.2. *Wood residues in the wood processing industry*

Three main types of residues are obtained by wood processing according to their size:

- bark,
- large remains after cutting and
- fine waste (sawdust, wood chips, wood dust).

The main part of the large residues can be recycled. Only a small part of residues remains unused to be used for other purposes, for example, making briquettes, bio-fuel or for energy production. Raw materials for production of solid bio-fuels (pellets, wood chips), depend on the market, that is whether the residues from different processes are going to be used to produce panels or pellets.

In well-organized companies that produce panels or pulp and paper, virtually all by-products, even wood residues, can be used internally. In sawmills a part is used internally, but a significant amount of residues is available for other needs, like for production of pellets, or for direct combustion and energy production. So, as a raw material for production of briquettes and pellets, the largest amount of wood residues comes from cutting wood in the forest and from sawmills. Other wood processing companies, especially the small ones, also have available sources of wood residues. Therefore, the total amount of wood residues for production of briquettes and pellets is estimated at about 1 million m^3, consisting of wood residues from wood cutting in the forest which is around 0.6 million m^3, around 360,000 m^3 from sawmills and no more than 50,000 m^3 of wood residues from other wood processing companies.

Wood wastes in sawmills are sawdust and scrap pieces. The amounts of residues vary depending on wood production capacity and facilities, but the average percentage is about 20% of the total mass of wood that is processed [41]. In order to get the right idea of the quantities of waste at sawmills an example is taken from a sawmill *Div-Chabros* form Loznica, in north-western Serbia. Field-based analysis shows the amount and type of wood that is processed in the wood industry Div-Chabros, residues from the production and calculations of waste that remains in the production process. The Div-Chabros company as part of its production has a line of final processing – production of parquet. Parquet production is done on an Italian machine type "Gabiano". The capacity of the quadrilateral Gabiano machine is 100–150 m^2 per shift, depending on the dimensions of the parquet. For the calculation a parquet plank sized 300 mm × 42 mm × 21 mm was taken, which gives us the freedom to argue that the capacity of the flooring line is 120 m^2 per shift.

Before making the budget it should be noted that in the production of parquet the parquet planks are called strips. The following calculation was carried out in order to calculate the waste of sawdust in the production of parquet:

- Strips average: 0.320 m × 0.050 m × 0.025 m = 0.0004 m^3.
- Parquet plank: 0.300 m × 0.042 m × 0.021 m = 0.0002646 m^3.

or participation of sawdust – waste: 33.85%.

If the daily use of strips for flooring is 30 m^2/m^3, the daily output is 120 m^2/30 m^2/m^3 = 4 m^3 of strips.

Working time is 25 days a month: 25 days × 4 m^3/day = 100 m^3 or the amount of waste is: 100 m^3 × 33.85% = 33.85 m^3,which is 680 kg/m^3 (abs. dry) × 1.08% = 734.4 kg, or, on a monthly basis: 734.4 kg × 33.85 m^3 = 24,859.44 = 24,860 t if the parquet planks humidity is 8%.

Calculations of sawdust and scrap pieces in sawmill processing show data on utilization of a cubic meter of log. The plan for cutting in the company Div-Chabros is 12,000 m^3 of logs annually, so the total waste is:

Sawdust – 12,000 m^3 × 13.04% = 1564.8 m^3 of wood mass in sawdust.
Waste wood – 12,000 m^3 × 26.84% = 3220.8 m^3 of timber.

Waste wood, regardless of place of origin, has the highest percentage and we get a total of 26.84% of waste wood that serves as raw material for production of wood briquettes. Two time smaller, but not insignificant, is the share or the residue of sawdust with 13.04% [42].

In addition to wood waste generated in production, it is important to draw attention to the large amount of wood residue that remains in the forest after exploitation. According to the estimates and data from primary and secondary research, and based on technological parameters on the amount of wood waste during the exploitation of forests we come to the fact that the amount of wood waste is approximately 176,292 m^3 annually [32]. This wood waste is currently not used for any purpose.

5.3. Wood waste management system

Generally accepted rule is that effective management of any waste includes three main levels: waste reduction, reuse and recycling. Wood waste is generated in all life stages of wood as material, and various wood residues occur in all stages of processing [41].

Overall, wood waste could be divided into those occurring in the production of final products (including trade) as a raw material, and the one that is made from already used wood products.

Prevention or reduction of waste at the source (waste minimization), rehabilitation of used items and their re-use (for the same or other purpose), that is reduction of use of resources and reduction of the quantity or hazardous characteristics of wastes, is the best approach to managing wood waste. It is followed by recycling or waste treatment in order to obtain raw materials for producing the same or other products. Utilization and use of waste (composting) is next the option but it is less desirable than the previous one. Waste whose generation cannot be prevented, which cannot be recycled or composted, can be properly incinerated or deposited [43].

Waste management is a system of activities that include prevention of waste generation, minimization of waste and its intrinsic properties, waste treatment, establishment, operation, closing and maintaining of facilities for waste treatment, monitoring, counselling and education related to activities in waste management, based on the principles of sustainable development and human principles of nature conservation.

Control of industrial waste, primarily non-hazardous, has no significant differences in relation to the treatment of municipal waste. Wood processing enterprises generate waste during processing (wood residues, sawdust) which is treated as a new resource for heating (pellets, briquettes).

Wood waste management has the same aim as any other kind of waste management, which, in this case, is reducing waste at sawmills and recycling. Recycling wood waste differs from other types of recycling, primarily because during this process a secondary raw materials and finished products are obtained.

By analyzing the situation in the industry we can point out several problems that arise in the field of creation and use of wood waste:

- Insufficient utilization of woody biomass;
- Lack of organization of the timber industry;
- Lack of knowledge of new technologies for using wood waste;
- Lack of markets for product made of wood waste;
- Environmental pollution with primary waste resulting from cutting and secondary waste that is left after the primary and final wood processing;
- Secondary (indirect) pollution from the use of other energy sources instead of wood waste;
- Lack of legislation on forest management and protection, environmental regulations for waste disposal and harmful gases emissions into the atmosphere;
- Insufficient level of incentives for the production and use of renewable fuels;
- Low awareness of the need to use renewable bio-fuels.

By removing these problems the benefits of development of production and use of wood waste products, primarily in terms of reducing the use of fossil fuels, increased use of energy generated

from renewable sources and environmental protection would be felt [32,41,43].

6. Wood briquettes

Briquettes made of wood shavings are the most economical way of using a solid resource for heating, on one hand, and cleanest way to heat homes or business premises on the other. The use of waste sawdust and coal dust in briquettes gives energy-caloric values higher than high-quality coal, and thereby contribute to the health of the environment immeasurably.

On the grounds that the briquettes are made from waste wood and coal dust, and that such use "cleans the environment", with the use of briquettes in any heating systems that uses solid fuel, no other by-products other than those defined by nature are created. So, there are no greenhouse gases and no large amounts of ash.

6.1. The technology of making briquettes

In order to bulky biomass reach the most remote users it needs to be compacted or be packed in form of best shape and size for handling, transporting, storing and preservation. In this way, biomass could become a market commodity, in other words it would be available to more consumers.

Briquetting of biomass shows a number of advantages over other processes of producing biomass. The volume, the cost of handling and transport are reduced, much less storage space is required, the resistance of material on deterioration in biological processes is greater and it increases efficiency in the combustion process.

The energy briquettes can be used in all types of furnaces that use solid fuel, with careful dosing [44]. By energy values briquettes are similar to brown coals from Serbia. In addition, the use of briquettes instead of coal has a significant environmental advantage, because the sulphur content which is here only in traces (less polluting with combustion products), and ash from briquettes can be used as a good fertilizer.

Briquettes are formed by pressing crushed particles of ligno-cellulosic material with or without a binder under certain conditions: high pressure, elevated temperature and optimal moisture content in the material. The piston impact pressure is 210 bars for briquettes without binder. In the pressing of biological material volume is reduced about 10 times, and by that a volumetric briquette mass of 800–1200 kg/m^3 is achieved. The temperature of press tools is 90 °C. Compactness and density of crushed particles in briquette without binder is provided by thermoplastic gluing of particles of plant material [45]. Apart the appropriate granulation (fragmentation) of the starting material (3–5 mm), material moisture content has an important role in pressing the biomass. The optimum moisture content is about 15%. The shape of briquettes is cylindrical. The diameter of briquettes can be from 25 to 90 mm and variable in length [46]. Briquettes are usually packed in thermo shrinking foil, cardboards, paper or plastic bags [44,47,48].

Technological process of briquetting of crushed ligno-cellulose material without binder is based on high pressure in the presses tool from 150 to 200 bars, which turns the biomass into briquettes that are compact and have a thigh-volume mass. In order to be able to convert biomass into a permanent firm form the moisture content must be 10% to 18% (up to 20%) and granulation of materials up to 5 mm. Therefore, to ensure these conditions it is necessary to naturally dry the biomass. By briquetting the volume of the biomass is reduced 7–12 times and the volume mass of obtained briquettes is 1.0–1.4 kg/dm^3. The briquettes are packed in cardboard boxes of 10 kg, plastic bags of 25–40 kg or in thermo shrinking plastic wrap. Packing of briquettes is necessary due to exceptional hygroscopicity of the compressed material [47,48].

The optimal technological process for the formation of high-quality energy briquettes is conditioned by the type of material, quality of fragmentation and by moisture content in the material. This procedure is very complex and expensive when an adhesive is used as bonding agent to connect fragmented particles. Adhesives accounted for 74% in the cost of briquetting [49]. These are the reasons why many owners of briquetting plants abandoned this method of briquettes production. Production of briquettes without the participation of binder (adhesive) significantly contributes to the cheapening of production processes and improves its ecological values. Also, the participation of sulphur is negligible (6 times less than coal), the amount of ash is 2–7 times less compared to coal and the moisture content is 2–5 times lower than in coal [50].

6.2. Calculation of calorific power of wood briquettes and equivalent heat energy sources

The company Div-Chabros from Loznica plans to manufacture 3300 tons of briquettes per year. As for the composition of the raw material for briquettes all raw material originates from beech. Calorific value of briquettes made of beech in the dry state with 12–15% of humidity is 21,683.48 kJ (5180 kcal). Calorific power of briquettes speaks of its energy value, and the higher it is, the greater is the amount of energy supplied by burning and the economical use is higher. Comparisons of calorific power of briquettes, with moisture of 10–12%, were made with the following fuels: I class oak firewood in m^3, I class beech firewood in m^3, I class ash firewood in m^3, comparison with lignite coal in tons, comparison with brown coal in tons, comparison with distilled oil in tons and comparison with natural gas in tons.

6.2.1. Comparison of calorific power of wood briquettes with 1 m^3 of I class oak wood

The average bulk density of oak in dried state is 750 kg/m^3 with the average calorific power of 14,444.46 kJ/kg. Calorific power of dried oak is obtained from the product of average volumetric weight and average calorific power, therefore caloric power of 1 m^3 of dried oak is: 14,444.46 kJ/kg × 750 kg/m^3 = 10,833,345 kJ/m^3.

The average calorific power of wood briquettes with 12–15% humidity is 21,683.48 kJ/kg. The total calorific power of 3.300 t of briquettes, as it was planned to be produced in DIV-Chabros company, amounts to 3,300,000 kg × 21,683.48 kJ/kg = 71,555,484,000 kJ.

Equivalent heat for 1 m^3 of oak wood is 6605.1, and the value derived from the ratio of the total calorific power of 3.300 t of briquettes and the average calorific power 1 m^3 of dried oak.

Et_{oak} = 71,555,484,000 kJ/10,833,345 kJ/m^3 = 6605.1 m^3.
Et_{oak} = 6605.1 m^3 oak wood.

6.2.2. Comparison of calorific power of wood briquettes with 1 m^3 of I class beech wood

One cubic meter of I class beech wood that is dried, has an average bulk density of 720 kg/m^3 and the calorific power of 14,842.20 kJ/kg.

The calorific power of 1 m^3 of beech will be: 720 kg/m^3 × 14,842.20 kJ/kg = 10,686,384 kJ/m^3.

The total calorific power of the briquettes is 71,555,484,000 kJ.

Equivalent heat:

Et_{beech} = 71,555,484,000 kJ/10,686,384 kJ/m^3 = 6695.9 m^3.
Et_{beech} = 6695.9 m^3 of beech wood.

6.2.3. *Comparison of calorific power of wood briquettes with 1 m^3 of I class ash wood*

One cubic meter of I class ash wood that is dried has the bulk density of 690 kg/m^3 and the calorific power of 16,077.30 kJ/kg.

Calorific power of 1 m^3 will be: 690 kg/m^3 × 16,077.30 kJ/kg = 11,093,337 kJ/m^3.

Total amount of briquettes calorific power is 71,555,484,000 kJ.

Equivalent heat:

Et_{ash} = 71,555,484,000 kJ/11,093,337 kJ/m^3 = 6450.3 m^3.
Et_{ash} = 6450.3 m^3 of ash wood.

6.2.4. *Comparison of calorific power of wood briquettes with 1 t of lignite*

Calorific value of lignite coal ranges from 8373.6 to 16,747.2 kJ/kg of dry coal. The average calorific power of 12,560.4 kJ/kg is taken for comparison.

One ton of lignite has the calorific power of 1.000 kg × 12,560.4 kJ/kg = 12,560,400 kJ.

The total calorific power of dry briquettes is 3,300,000 kg × 18,597.765 kJ/kg = 87,297,672,000 kJ.

Equivalent heat:

$Et_{lignite}$ = 87,297,672,000 kJ/12,560,400 kJ/t = 6950.2 t.
$Et_{lignite}$ = 6950.2 t of lignite coal.

6.2.5. *Comparison of calorific power of wood briquettes with 1 t of brown coal*

Calorific power of brown coal in the dry state ranges from 16,747.2 to 20,934 kJ/kg. For the calculation we took the average calorific power of 18,840.6 kJ/kg.

One ton of brown coal has a calorific power of 1000 kg × 18,840.6 kJ/kg = 188,406,000 kJ.

The total calorific power of the briquettes with 0% moisture is 87,297,672,000 kJ.

Equivalent heat:

$Et_{brown\ coal}$ = 87,297,672,000 kJ/188,406,000 kJ/t = 4633.5 t.
$Et_{brown\ coal}$ = 4633.5 t of brown coal.

6.2.6. *Comparison of calorific power of wood briquettes with 1 t of distilled oil*

Calorific value of 1 kg of distilled oil is 41,239.98 kJ/kg.

One ton of distilled oil has a calorific value of 1000 kg × 41,239.98 kJ/kg = 412,399,800 kJ.

The total calorific power of the briquettes in a dry state is 87,297,672,000 kJ.

Equivalent heat:

$Et_{distilled\ oil}$ = 87,297,672,000 kJ/412,399,800 kJ/t = 2116.8 t.
$Et_{distilled\ oil}$ = 2116.8 t of distilled oil.

6.2.7. *Comparison of calorific power of wood briquettes with natural gas for household (such as propane or butane)*

Calorific value of gas for households is 45,636.12 kJ/kg.

1 t of gas for households has a calorific power of 1000 kg × 45,636.12 kJ/kg = 456,361,200 kJ.

The total calorific value of briquettes in the dry state is 87,297,672,000 kJ.

Equivalent heat:

Et_{gas} = 87,297,672,000 kJ/456,361,200 kJ/t = 1912.9 t.
Et_{gas} = 1912.9 t of gas.

Based on the calculation it can be concluded that the total annual wood waste from only one sawmill in Serbia can get enough briquettes for the substitution of 6605 m^3 of oak wood, 6950 t of lignite coal, 4633 t of brown coal or 1912 t of gas for households, which are not negligible amounts of energy.

To present the characteristics and the energy value of briquettes and pellets in comparison to other fuels, we have used tables which were made by European companies. Foreign producers are much more concerned with this issue, while our knowledge of briquettes is vast they are rarely used. It is difficult to present a calculation that shows the advantages of using briquettes from an example from Serbia. That is why, in this case, experiences of foreign manufacturers from Germany, Sweden and Denmark are used [51].

From Table 4 it can be concluded that the briquettes and pellets have remarkable energy potentials and that the amount of ash is much lower compared to coal.

7. Market, economics and policy

Briquette market in Serbia is not developed because, in order to exist, we need companies involved in this activity and products consumers. Serbia has companies that produce wood briquettes and pellets, but they do not have consumers in this area, so all the produced quantities are exported. The number of companies involved in this production is definitely growing, and there are hints for explosive growth of briquette manufacturers. The introduction of this product in everyday life includes the installation of special equipment like boilers for heating. The price of pellet boilers is far higher than the price of gas pipelines and they represent an unreachable investment for the average household in Serbia. In Serbia today, except in major cities, one cannot buy a pellet boiler, and it is even harder to find professionals who will install and maintain them. Serbia has the raw materials, domestic producers and technology, foreign investments and support from international organizations for the use of pellets and other forms of biomass [32]. However, there is no legislation, built awareness of the economic and environmental feasibility of using this type of energy and the concept of what is the energy future of Serbia.

Raw material for production of wood pellets can be purchased directly from the forest or from sawmills. If a manufacturer of wood pellets needs to supply with wood waste directly from the forest then the price of wood waste would not be more than 25 Euros/t [39]. Assuming that the transport of wood waste by a truck is similar to the transport of coal where the price of transport ranges from 0.7 to 1.4 Euro/km for distances up to 50 km for a truck with capacity of 25 t. Transforming this cost per ton of briquettes, we get the price of 1.8–3.6 Euros/t. Price depends a lot on transport density of wood waste.

Based on the aforementioned briquette plant should, for the practical and economic reasons, be within the area where the wood production is, as this would reduce transportation costs of raw materials. Looking from the aspect of the environment and its conservation, production of briquettes and establishing plants for briquette or pellet production are significant [54]. In addition to solid pieces of wood for sawdust is also used manufacturing briquettes, which an issue in every sawmill because of its disposal. The sawdust itself is not harmful to the environment as long as it is not kept for a long time. Sawdust, in contact with rainwater, produces phenol and manganese, which are harmful to human health [55], which is another proof why we should use sawdust for the production of briquettes. Otherwise, the place where the sawdust is deposited, which are mostly free areas on the land where the sawmill is, eventually require rehabilitation, and in order to rehabilitate holes that are 3–4 m deep need to be dug in the ground, depending on the amount deposited sawdust

Table 4
Comparative review of calorific power of certain fuels.

Type of fuel	Weight in kg/m^3	Humidity in %	Quantity of ash in %	Caloric value in MWh/Mt
Briquette	550–650	10	0.4–0.6	4.65–4.75
Pellet	600–700	9	0.6–0.8	4.75–4.85
Sawdust	cca 200	8	0.4–0.6	4.80–4.90
Wood chips	250–350	50	0.4–3.0	2.25–2.35
Distilled oil	830	0	0	9.90
Coal	830	5	3–5	9.90

Source adapted from Refs. [51–53].

and the time of deposition. Only in such way soil and groundwater contamination would be prevented. It should be noted that these rehabilitation processes in Serbia are not done. This is usually solved by transportation of sawdust at the city dump [56], which afterward remains the responsibility of the people who control the operation of landfills and the polluter has nothing more to do with it.

Given that Serbia has good potentials for developing the sector of renewable sources and biomass production, the Ministry of Mines and Energy of the Republic of Serbia and the NL Agency from the Netherlands (formerly SenterNovem – Agency of the Ministry of Economic Affairs of the Netherlands) created a Biomass Action Plan 2010–2012, in the Serb-Dutch project at the government level on biomass and bio-fuels. The project should encourage the use of biomass for heat and electricity, and the establishment of companies in this field [32].

Estimating the total consumption of wood for energy, including wood which has been cut down and recorded in private forests and one that was not recorded, firewood from state forests and wood cut outside of forests, it can be estimated that the total annual consumption of firewood is not below 3.5 million m^3. Reduction of the consumption of firewood imposes a need for production of alternative means that can be used for such purposes, which, in this case, was the production of briquettes. This would reduce the amount of wood that is used for heating, by using waste generated in wood industry production processes [57]. If aforementioned is to be achieved it is necessary to have the support of the state that would accept and support innovations in industrial production.

Currently there is no developed market for the briquettes in Serbia. With the formation of markets the transfer of knowledge and technology from other countries would help a lot. The financial support of the state, which can be achieved through a system of non-repayable subsidies, is crucial. It is essential that favourable credit support for investors is established as soon as possible as well as a support for foreign investment. Biomass capacity development must be in accordance with building the capacity for their production. Otherwise, it is necessary to import these fuels.

The support for producers of wood biomass should be achieved through:

- subsidies for raising dedicated fast-growing forest plantations;
- incentives for biomass delivered to the domestic market;
- support to private forest owners for biomass production through rural development funds;
- disincentives for exporting woody biomass and products of woody biomass;
- giving priority in supplying with raw materials for domestic consumers of biomass, by public enterprises for the management of state forests [32].

The legal conditions for the production and use of fuel made from wood in Serbia, the use and production of woody biomass as energy sources and more intensive use of this energy source does not exist. In the forestry sector the importance of woody biomass as energy sources is becoming more and more an object of interest. One of the documents governing this issue is the “Regulation on the measures of incentives for the production of electricity by using renewable energy sources and by combined production of heat and power” which was adopted by the Serbian Government in the year 2009.

The Regulation provides the following:

- measures of economic policy will stimulate consumption of wood for energy fuel, and also provide troubleshooting for forests where firewood is the main product;
- the importance of intensive forest plantations as a sustainable and environmentally correct renewable energy and raw materials sources for industry, which will alleviate pressure on natural forest resources;
- initiate research on the role of forests in mitigating the problems of the energy balance of the country;
- increase the forest area by encouraging and assisting the activities of afforestation of land on which it is economically and environmentally justified to grow a forest [57].

In the plans for the development, there are two scenarios by the year 2015. One is to retain the present state of forest roads, which means only 50% utilization of forests. In this case, the total deforestation would be slightly increased on the basis of reforestation in the past. The second scenario is based on the assumption that the new forest roads will be constructed and the existing will be improved. This would lead to large-scale deforestation, leading to a level of utilization of about 75%, as it is in developed countries.

Without the introduction of measures to improve forestry, the total installed capacity of the wood briquettes and pellets factories could be up to 500,000 t in 2015, which would use 1 million m^3 of wood waste. If the forestry is improved and the level of utilization is increased from 50% to 75%, then the available amount of wood waste would be increased to 1.4 million m^3, which would enable the production of wood briquettes and pellets in the amount of 700,000 t per year. It is assumed that the consumption of fuel wood will not grow in the coming years. This assumption is based on the expectation that wood residues and wood briquettes and pellets will be cheaper than the cut logs that are used as firewood, and that the logs will be used to manufacture various wood products that would bring more income than firewood [32].

By briquetting process the volume of bulky biomass is reduced 10–12 times. Density of briquettes is 1000–1400 kg/m^3, and the bulk weight is from 400 to 600 kg/m^3. In this way prepared biomass is a suitable good for the market. It can be easily manipulated, easily transported, stored and preserved. The ratio of invested and potentially obtained energy in the process of biomass production is approximately 1:8.40. For optimal quality briquetting of biomass moisture content in plant material should range from 14% to 18%. At lower and higher moisture content the form of briquettes is not persistent. Production of briquetting presses requires great expertise and well equipped machine industry, for briquetting conditions, high pressure and temperature, condition using special materials, high accuracy in the preparation of cylinders, pistons and presses and a high-quality heat treatment.

The price of briquetted and pelleted biomass without binding agents in Vojvodina is from 100 to 120 Euros/t of briquettes. If binders are added the price of briquettes grows. In order to lower the costs of briquetting and pelleting the cost of grinding the biomass should be reduced. Wet biomass must not be dried artificially because of the large expenditure of energy, but dried naturally by draft. Briquettes formed from crushed material have better mechanical properties and are more stable during storage and transport, but the proportion of energy invested in the shredding of the material significantly increases. For economical biomass briquetting a cheap binder that could reduce the invested electricity should be found. Cost of briquettes and pellets production depend on the type of raw material, way of collection, collection techniques, transport and storage, types of pressing lines, molding technology, the type of packaging, line performance, the number of workers involved, the value of the building and equipment, interest on loans, etc. When everything is taken into account the cost of production of briquettes and pellets from sawdust is 100 Euros/t, and from crop residues from agriculture up to 120 Euros/t. On the domestic market which is not yet developed, the selling price of briquettes and pellets in bulk and wholesale is 100 Euros/t, and in retail 150 Euros/t packed in sacks. The price of briquettes and pellets intended for the European market is 100 Euros in bulk, 200 Euros packed in large bags and 300 Euros packed in small bags, but they must be produced according to European CEN standards or according to the standards of the country in which the briquettes or pellets are sold. The profit (earnings) from the production and sale of briquettes and pellets is still not significant in the domestic market. To expand this production and to become profitable the help of the state, banks and donors is necessary. Interest on loans should not be high, because the funds can be fairly quickly returned, especially if the briquettes and pellets are going to be exported to the developed European market [50].

8. Conclusion

Current level of energy production in Serbia satisfies merely 25% of the country's needs making Serbia increasingly dependent on energy imports. It is estimated that Serbia will exhaust its current coal supplies within the next 55 years, and oil and gas within 20 years. As regards consumption, it is estimated that the overall energy consumption is in favour of fossil fuels 93%, leaving only 7% for renewable sources. According to some assessments, so far merely 20–25% of the total renewable energy capacity has been used. Around 80% of unused potential is in biomass exploitation (wooden and agricultural biomass), whereas the remaining 20% consist of micro hydro-plants and geothermal sources. Biomass potential could be used to replace 25% of the current total energy production in Serbia. There is a strong potential for energy wood growing on about 200,000 ha of uncultivated soil.

When it comes to woody biomass, by primary wood processing in sawmills there is more than 20% of residues which are mostly deposited without further exploitation. Single piece waste, sawdust, bark and other waste of timber, which are mechanically treated, become important raw materials for production of briquettes, but as such, can be delivered as raw materials to companies that make wood pellets and briquettes. By using wood waste as secondary raw material, we get a starting raw material for production of wood briquettes, which would mean that everything that was so far unexploited mass becomes useful for further production. The usefulness is reflected in many aspects, particularly economic, because producing organic products in the wood industry does not require that the wood processor-manufacturer has a briquetting plant, but can deliver its starting material to other manufacturers, for adequate compensation.

Although a lot is known about renewable energy, biomass and its importance, the benefits of using and producing wood briquettes and pellets, there are problems which are encountered in the field of creation and utilization of wood waste. They are related to underutilization of timber, lack of knowledge of new technologies for exploiting wood waste, lack of market for products made from wood waste, pollution of the environment with primary and secondary waste, non-application of legislation on forest management and protection, environmental regulations for disposal of waste and emissions of harmful gases into the atmosphere, an insufficient level of incentives for production and use of renewable fuels and low awareness of the need to use renewable bio-fuels.

Resolving these issues would open some new paths from which everyone would benefit: the existence of available sources of raw materials and the optimal use of resources; development of new industries with significant potential; the introduction of new technologies that help reduce environmental pollution; employment in the industry (forestry, wood production) in undeveloped rural areas where there is a large number of unemployed; creating a market for wood waste products; savings in using renewable energy sources; reducing the use of other fuels; environmental protection; involvement in European development processes and the availability of development funds.

Acknowledgements

The authors would like to express their sincere thanks to the Ministry of Science and Technological Development, Republic of Serbia – Project No. 176020, and to the Provincial Secretariat for Science and Technological Development of the Vojvodina Province, Republic of Serbia – Project No. 114-451-1861/2011-02, for their financial support.

References

[1] Saidur R, Abdelaziz EA, Demirbas A, Hossain MS, Mekhilef S. A review on biomass as a fuel for boilers. Renewable and Sustainable Energy Reviews 2011;15:2262–89.
[2] Aswathanarayana U. Renewable energy policy. In: Aswathanarayana U, Harikrishnan T, Thayyib Sahini KM, editors. Green energy: technology, economics and policy. London: CRC Press, Taylor & Francis Group; 2010. p. 269–79.
[3] Brkić M. Dostignuća u korišćenju biomase u Danskoj i Švedskoj. Traktori i Pogonske Mašine 2002;7(3):50–5.
[4] Dodić S, Popov S, Dodić J, Ranković J, Zavargo Z, Golušin M. An overview of biomass energy utilization in Vojvodina. Renewable and Sustainable Energy Reviews 2010;14:550–3.
[5] Dodić S, Popov S, Dodić J, Ranković J, Zavargo Z. Biomass energy in Vojvodina: market conditions, environment and food security. Renewable and Sustainable Energy Reviews 2010;14:862–7.
[6] Dodić S, Vučurović D, Popov S, Dodić J, Zavargo Z. Concept of cleaner production in Vojvodina. Renewable and Sustainable Energy Reviews 2010;14:1629–34.
[7] Dodić SN, Zekić VN, Rodić VO, Tica NLj, Dodić JM, Popov SD. Analysis of energetic exploitation of straw in Vojvodina. Renewable and Sustainable Energy Reviews 2011;15:1147–51.
[8] Ostojić M, Simin R, Igić S. Upotreba biomase za proizvodnju toplotne energije na farmi. Časopis za Procesnu Tehniku i Energetiku u Poljoprivredi 2003;7(5):121–3.
[9] Dodić SN, Zekić VN, Rodić VO, Tica NLj, Dodić JM, Popov SD. Situation and perspectives of waste biomass application as energy source in Serbia. Renewable and Sustainable Energy Reviews 2010;14:3171–7.
[10] Igliński B, Iglińska A, Kujawski W, Buczkowski R, Cichosz M. Bioenergy in Poland. Renewable and Sustainable Energy Reviews 2011;15:2999–3007.
[11] Golusin M, Tesic Z, Ostojic A. The analysis of the renewable energy production sector in Serbia. Renewable and Sustainable Energy Reviews 2010;14:1477–83.
[12] Aswathanarayana U. Biomass. In: Aswathanarayana U, Harikrishnan T, Thayyib Sahini KM, editors. Green energy: technology, economics and policy. London: CRC Press, Taylor & Francis Group; 2010. p. 29–38.
[13] Stanković L, Bugarin R, Zagorac R, Samardžija M. Presovanje otpadaka biomase radi zaštite životne sredine i stvaranje kvalitetnih goriva. Zbornik radova Biomasa Ekološki Pokret Jugoslavije 1995:169–75.
[14] Jovanovska V, Jovanovski N. Agriculture and biomass energy. Časopis za Procesnu Tehniku i Energetiku u Poljoprivredi 2008;12(3):183–5.
[15] Janić T, Brkić M, Igić S, Dedović N. Biomasa – energentski resurs za budućnost. Savremena Poljoprivredna Tehnika 2010;36(2):167–77.

[16] Đorđević B. Objektivno vrednovanje obnovljivih energija. Vodoprivreda 2008;40:19–38.
[17] Ajanovic A. Biofuels versus food production: does biofuels production increase food prices? Energy 2011;36:2070–6.
[18] Dodić S, Popov S, Dodić J, Ranković J, Zavargo Z. Potential contribution of bioethanol fuel to the transport sector in Vojvodina. Renewable and Sustainable Energy Reviews 2009;13:2197–200.
[19] Government of the Republic of Serbia, Ministry of Mining and Energy. Energy Sector Development Strategy of the Republic of Serbia by 2015, Official Gazette RS 44/2005.
[20] Government of the Republic of Serbia. Energy law, Official Gazette RS 84/2004.
[21] Dakić D, Erić A, Đurović D, Erić M, Živković G, Repić B, et al. Jedan od načina korišćenja nus proizvoda iz poljoprivredne proizvodnje kao goriva. Časopis za Procesnu Tehniku i Energetiku u Poljoprivredi 2009;13(1):81–4.
[22] Martinov M, Tešić M, Konstantinović M, Stepanov B. Perspektive u korišćenju biomase za grejanje domaćinstava u seoskim područjima. Savremena Poljoprivredna Tehnika 2005;31(4):211–20.
[23] Vlada Republike Srbije. Zakon o zaštiti vazduha, Službeni Glasnik RS 36/2009.
[24] Vlada Republike Srbije. Zakon o zaštiti životne sredine, Službeni Glasnik RS 72/2009.
[25] Omer AM. Green energies and the environment. Renewable and Sustainable Energy Reviews 2008;12:1789–821.
[26] Tešić M, Kiss F, Zavargo Z. Renewable energy policy in the Republic of Serbia. Renewable and Sustainable Energy Reviews 2011;15:752–8.
[27] Vlada Republike Srbije. Zakon o ratifikaciji Kjoto Protokola, Službeni Glasnik RS 88/2007 i 38/2009.
[28] Bogunović A, Bogdanov N. Analysis of renewable energy and its impact on rural development in Serbia. Enlargement network for Agripolicy Analysis, AgriPolicy; 2009. http://www.euroqualityfiles.net/AgriPolicy/Report%202.2/AgriPolicy%20WP2D2%20Serbia%20Final.pdf (accessed on 30.07.2011).
[29] Di Giacomo G, Taglieri L. Renewable energy benefits with conversion of woody residues to pellets. Energy 2009;34:724–31.
[30] Jezdimirović J, Mitrović S. Korišćenje biomase kao alternativnog izvora energije. Zbornik Naučnih Radova Instituta PKB Agroekonomik 2010;16(1–2):275–83.
[31] Mitić D, Milanović B, Stanković P, Mihajlović E, Janković S. Produkcija CO i CO_2 pri sagorevanju biobriketa od biomase. Časopis za Procesnu Tehniku i Energetiku u Poljoprivredi 2000;4(3–4):72–5.
[32] Republika Srbija, Ministarstvo rudarstva i energetike, NL Agency. Akcioni plan za biomasu 2010–2012; 2010. http://www.ssl-link.com/mre/cms/mestoZaUploadFajlove/BAPsrpski.pdf (accessed on 02.08.2011).
[33] Pejanović R, Jelić V, Zekić V, Brkić M. Ekonomski pokazatelji sagorevanja peletirane biomase. Savremena Poljoprivredna Tehnika 2010;36(4):411–9.
[34] Medarević M, Banković S, Šljukić B. Sustainable forest management in Serbia – state and potentials. Bulletin of the Faculty of Forestry 2008;97:33–56.
[35] Aleksić P, Vučićević S. Šumovitost Srbije. Šumarstvo 2006;58(3):177–84.
[36] Vlada Republike Srbije. Zakon o šumama, Službeni Glasnik RS 30/2010.
[37] Banković S, Medarević M, Pantić D, Petrović N, Šljukić B, Obradović S. The growing stock of the Republic of Serbia – state and problems. Bulletin of the Faculty of Forestry 2009;100:7–30.
[38] Statistički godišnjak. Republički Zavod za statistiku Republike Srbije, Beograd; 2009.
[39] Informator Javnog preduzeća Srbijašume. JP Srbijašume, Beograd; 2009.
[40] Brkić M, Janić T. Poljoprivreda kao potrošač i proizvođač energije. Savremena Poljoprivredna Tehnika 2005;31(4):155–61.
[41] Milosavljević MM, Mihailović V. Vrste drvnog otpada, mesta nastanka i mogućnosti njegove primene. Prerada Drveta 2006;14:46–50.
[42] Interna dokumentacija pilane DIV-Chabros, Loznica, 2009.
[43] Vlada Republike Srbije. Zakon o upravljanju otpadom, Službeni Glasnik RS 36/2009.
[44] Brkić M, Janić T. Analiza postupaka briketiranja biomase. Savremena Poljoprivredna Tehnika 2003;29(4):217–22.
[45] Brkić M, Janić T. Oprema i tehnološki postupci za peletiranje biomase. Savremena Poljoprivredna Tehnika 2010;36(4):387–96.
[46] Brkić M, Janić T. Standards for pelleted and briquetted biofuels. Contemporary Agricultural Engineering 2009;35(4):260–7.
[47] Urbanovičová O, Piszczalka J, Lisowsk A, Findura P. Mechanical characteristics of briquettes made of biomass. Contemporary Agricultural Engineering 2010;36(4):397–400.
[48] Danilović M, Ilić M. Savremene tehnologije iskorišćavanja šumske biomase za energiju. Traktori i Pogonske Mašine 2006;11(3–4):121–8.
[49] Ostojić D. Ekološke vrednosti briketa. Zbornik Radova Značaj i Perspektiva Briketiranja Biomase 1996:39–46.
[50] Brkić M, Janić T. Briketiranje i peletiranje biomase. Savremena Poljoprivredna Tehnika 2008;34(1–2):78–86.
[51] Martinov M, Tešić M, Veseliniov B, Đatkov Đ, Bojić S. Primena čvrste biomase kao goriva u Nemačkoj – stanje i perspektive. Savremena Poljoprivredna Tehnika 2010;36(2):157–66.
[52] Amandus Kahl. Prospektni materijal. Hamburg, Nemačka: Amandus Kahl GmbH; 2009.
[53] Bogma AB. Ulricehamn. Sweden: Bogma AB; 2011. http://www.bogma.com/eng/index.htm (accessed on 10.08.2011).
[54] Bohlin F, Vinterbaock J, Wisniewski J. Solid biofuels for carbon dioxide mitigation. Biomass and Bioenergy 1998;15:277–81.
[55] Zoranović M, Bajkin A, Potkonjak V. Energetski i ekološki efekti sistema za prečišćavanje vazduha u procesu sagorevanja biomasenih goriva. Savremena Poljoprivredna Tehnika 2010;36(1):53–67.
[56] Nađ I. Urbana ekologija kao interdisciplinarna i primenjena naučna disciplina o životnoj sredini. Zbornik Radova Departmana za Geografiju, Turizam i Hotelijerstvo 2010;39:66–81.
[57] Vlada Republike Srbije. Uredba o merama podsticaja za proizvodnju električne energije korišćenjem obnovljivih izvora energije i kombinovanom proizvodnjom električne i toplotne energije, Službeni glasnik RS br. 99/09.